Research into Net Assessment of System Lifecycle for Teleoperation of Deep Space Mission

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***Abstract*—Critical elements in deep space mission reside in that the rover travels over the surrounding undetermined environment of planet and conducts scientific exploration under the ground control via teleoperation system. Such a teleoperation system plays a vital role in the whole deep space mission. Different from other information systems, the teleoperation system cannot be modified once the deep space mission has been launched. Therefore, it must be assessed quantitatively before and during its implementation. Following the "Net Assessment" theory in the field of national defense and taking national military software standards as baseline, the system development process net assessment model covering "Man, Machine, Material, Method, and Environment (4M1E)" is established in this paper. Then the Net Assessment Method (NAM) combined with the Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM) is proposed to solve the weight vector. In the final part of this paper, the teleoperation system for China's Chang'e 3 (CE-3) and Chang'e 4 (CE-4) deep space missions is employed as a case study to verify the applicability of this study, meanwhile the untrustworthy elements of the teleoperation system are discovered upon the net assessment result. The work completed in this paper is beneficial to the development process improvement of military information system.**

***Index Terms*—deep space mission, teleoperation system, system lifecycle, net assessment, process improvement**

I. INTRODUCTION

THE teleoperation system is essential during the rover travels over the surface of the planet, which plays a vital role in deep space mission. Since US launched the first lunar probe Pioneer-0 in August 1958 to China's CE-4 probe soft landing on the far side of the Moon in January 2019, there are more than 240 deep space missions have been accomplished. At the same time a lot of techniques such as hard landing, soft landing, teleoperation of rover and automated sampling have been verified successfully [1]. However, due to the technologies such as computers, artificial intelligence and communications are still immature, it is hard to conduct fully autonomous exploration in the deep space mission in a short term. In addition, it is highly dangerous that astronauts perform space tasks out of spacecraft in the harsh aerospace environment [2].

The teleoperation system is a part of the ground application system in deep space mission. It performs reconstruction of planet terrain, vision-based navigation and localization, path planning for safe movement and motion planning of the robotic arm for scientific probing. Firstly, it receives the high speed Tracking, Telemetering and Command (TT&C) data consists of the images of planet surface and the position and motion posture data of the rover from the TT&C station. Then it simulates the state that the rover travels over the surface of the planet to verify planning results in virtual control environment. At the same time, it generates the motion instruction sequence for next moving target and transmits optimal control command to the rover to achieve the teleoperation of the rover [3].

However, with the increasing difficulties of deep space mission, the related information processing systems often run error. There are a lot of space disasters caused by software bugs such as the explosion of the Ariane 5 launcher on its maiden flight in 1996, the loss of the Mars Climate Orbiter in 1999, the placing of a military satellite in an incorrect and unusable orbit by the Titan IV in 1999, the loss of contact with the Solar Hemispheric Observatory spacecraft in 1998 and so on. A series of software-related space disasters show that aerospace information processing systems are not always trustworthy [4].

In deep space mission, the spatial isolation of the control unit and the execution unit leads to the inevitable time delay in the teleoperation control loop. The intelligence level of spacecraft also determines the cooperation mode between the ground control center and the spacecraft. And various uncertainty factors in deep space mission will also bring about safety issues that cannot be ignored. Moreover, different from those information systems in other fields, the teleoperation system cannot be modified or replaced once the deep space mission has been launched. So, it is necessary to control the development process of teleoperation system strictly. That is, the teleoperation system must be assessed quantitatively before and during its implementation to ensure the success of deep space mission.

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II. Related Work

What users care about is whether the teleoperation system can work stably and provide them the expected service. The quantitative assessment is the most effective method to address this problem [5]. However, there is still no consensus on information system quality assessment. The Computing Research Association (CRA) and Defense Advanced Research Projects Agency (DARPA) in the United States have regarded the high-trust systems as one of the top five challenges that must be addressed in the field of information systems research. Europe launched the "Open Trusted Computing" research program in 2006. The National Security Agency (NSA) proposed Trusted Software Methodology (TSM) which includes forty-four basic principles of software credibility to ensure the credibility of its software development by assessing the behavior and capabilities of the software development process. For decades, a lot of scholars and research organizations from different countries have established various frameworks and methods for information system assessment from different perspectives based on their research fields.

Behshid Behkamal [6] held that a software quality model acts as a framework for the evaluation of the attributes of an application that contribute to the software quality. He presents a quality model for evaluation of B2B applications. Firstly, the most well-known quality models are studied. And reasons for using ISO/IEC 9126 quality model as the basis are discussed. The model quality in his paper is customized in accordance with special characteristics of B2B applications. The customization is done by extracting the quality factors from web applications and B2B e-commerce applications, weighting these factors from the viewpoints of both developers and end users, and adding them to the model. Jeffrey Voas [7] believed that software quality is the composition of some or all of the following non-functional attributes: Reliability (R), Availability (A), Fault tolerance (F), Testability (T), Maintainability (M), Performance (P), software Safety (Sa), and software Security (Se). If software quality is truly a combination of the aforementioned non-functional attributes, then software quality (Q) should be measurable via an equation that resembles something like the following: $Q=a*R+b*A+c*F+d*T+e*M+f*P+g*Sa+h*Se$. Where a, b, c, d, e, f, g, h are attribute weight coefficient. K Lis [8] held that issue of the computer software quality has an interdisciplinary nature. It is a subject of research in numerous scientific disciplines including the software engineering, economics, psychology and ergonomics. The developed model in his paper demonstrates that the software quality may not be based only on experience and skills. But it must extend over details concerning economic and social conditions. E Utami [9] determined the quality assessment of software based on two main stages. The first stage is to determine the weight of traditional metrics and software quality factors by using AHP. The second stage is to search the final score and ranking. Yang Y R [10] investigated the multiple attribute decision making problems for evaluating the software quality with triangular fuzzy information. Then, they extend the Grey Relational Analysis (GRA) procedure for triangular fuzzy multiple attribute decision making for evaluating marine service industry in triangular fuzzy setting. According to the concept of the GRA, a fuzzy relative relational degree is defined to determine the ranking order of all alternatives by calculating the degree of fuzzy grey relational coefficient to both the Triangular Fuzzy Positive-Ideal Solution (TFPIS) and Triangular Fuzzy Negative-Ideal Solution (TFNIS) simultaneously. Miltiadis G [11] introduced an adaptive integrated framework for software product quality assessment that applies static analysis to benchmark repositories in order to generate a software quality model tailored to specifications. Then the fuzzy multi-criteria decision-making is employed to model the uncertainty imposed by experts' judgments.

In this paper, the net assessment of teleoperation system can be divided into two steps from the perspective of information system development process.

1) *Establishment of net assessment model.* Following the "Net Assessment" theory in the field of national defense and taking national military software standards as baseline, the system development process net assessment model covering "Man, Machine, Material, Method, and Environment (4M1E)" is established in this paper. This net assessment model consists of Organization, Environment, Management, Code and Document.
2) *Solution of the weight vector.* The NAM is proposed to solve the multi-attribute decision-making problem in net assessment model, which is more accurate and scientific than AHP and EWM.

The work completed in this paper has been applied in the development process control and management of the teleoperation system of China's "Jade Rabbit" rover in CE-3 and CE-4 lunar exploration missions successfully. Besides, it has been implemented in China's Chang'E-5 (CE-5) deep space mission. What's more, it will be promoted in the Mars exploration mission in 2020.

III. Net Assessment

A. Net Assessment Theory

Net assessment [12] was first adopted by US military, due to its superior performance on comparative analyses, diagnostic and prospective evaluation for multi-disciplinary. The US Department of Defense (DOD) has a deeply comprehension on the definition, core content and architecture of net assessment, which was obtained from decades of practical application. For example, DOD submits military strength net assessment report on its competitors regularly, such as the former Soviet Union and China [13]. The centre of strategic and budgetary assessments is the consultant for US national security strategy and defense planning proposal. Besides, it also predicts the mode of future war which depends on inference methods. The net assessment was extensively used by a lot of countries such as Japan, India, Australia, and Israel, which has great popularity and influence for the whole world. However, there is no research on the net assessment in deep space mission field. Min Tang [14] established an evaluation index system of national military development according to the net assessment and calculates the assessed value of national military development using the statistical methods. Based on the evaluation index system, he evaluates the priority degree of China and Japan military development to 2020. Stephen Peter Rosen [15] introduced the founder of net assessment Andrew Marshall and reexamines the impact of the office of net assessment on the American military in the matter of the revolution in military affairs. G L Yan [16] presented the detail definition, basic characteristics, analytical framework and implementation steps of net assessment, who held that the net assessment applied in different fields has the same implementation steps including summary, verification, integration and comparison. B S Yi [17] held that net assessment has formed a stable model in the past 40 years. That is Strengths Weaknesses Opportunities Threats (SWOT) analysis model. And, he summarizes the common means of net assessment such as scene analysis method, imaginary enemy mechanism and model simulation tool.

This paper introduces the net assessment theory into the field of aerospace information system engineering for the first time. Different from the traditional software quality evaluations model and method, the net assessment model and the NAM proposed in this paper also have two features: comprehensiveness and objectiveness.

1) According to total quality management theory, the net assessment model based on national military standards covers five aspects: “Man, Machine, Material, Method, and Environment (4M1E)”. Additionally, it involves all phases of the software lifecycle including software requirements analysis, outline design, detailed design implementation, testing and maintenance. What’s more, it takes the social environment, physical environment, personnel capabilities and process management into consideration to ensure the accuracy and comprehensiveness of the net assessment model [18].
2) The assessment elements of the net assessment model must be Boolean type, which avoids the man-made interference extremely. Besides, the NAM combines the advantages of AHP which is a subjective weighting method and EWM which is a subjective weighting method. And, the consistency checking ensures the consistency of the reciprocal judgment matrix. Finally, the uncertainty cognitive is reduced by solving experts’ “Cognitive Blindness” [19, 20].

B. Net Assessment Model

Currently, there are many popular models in software quality control such as the McCall Model, Boehm Model, TRUSTIE model, FURPS/FURPS+ model, Dromey model, IT Security Evaluation Standard (ISO/IEC 15408), Software Product Evaluation Standard (ISO/IEC 9126), Software Life Cycle Processes Standard (ISO/IEC 12207), Software Process Improvement and Capability Determination Standard (ISO/IEC 15504), Open Source Maturity Model (OSMM), Open Business Readiness Rating (OpenBRR), Capability Maturity Model Integration (CMMI) [21-25] and so on. Among them, the CMMI and ISO/IEC 9126 are most widely used for software quality assessment.

CMMI is a process-oriented information system quality model. It splits the information system development process into twenty-two Process Areas (PA) from four aspects: process management, project management, engineering management and support management of software development. It divides capability maturity into five Maturity Levels (ML): Initial Level (ML1), Managed Level (ML2), Defined Level (ML3), Quantitative Management Level (ML4) and Continuous Optimization Level (ML5). Each ML contains different process areas. The corresponding relationship between ML and PA is shown in Table Ⅰ.

TABLE I
THE CORRESPONDING RELATIONSHIP BETWEEN ML AND PA

ML	PA
ML2	Configuration Management (CM)
	Measurement and Analysis (MA)
	Process and Product Quality Assurance (PPQA)
	Project Monitoring and Control (PMC)
	Project Planning (PP)
	Requirements Management (REQM)
	Supplier Agreement Management (SAM)
ML3	Decision Analysis and Resolution (DAR)
	Integrated Project Management (IPM)
	Organizational Process Definition (OPD)
	Organizational Process Focus (OPF)
	Organizational Training (OT)
	Product Integration (PI)
	Requirements Development (RD)
	Risk Management (RSKM)
	Technical Solution (TS)
	Validation (VAL)
	Verification (VER)
ML4	Organizational Process Performance (OPP)
	Quantitative Project Management (QPM)
ML5	Causal Analysis and Resolution (CAR)
	Organizational Performance Management (OPM)

CMMI is a tree model, as shown in Figure 1. Each PA includes several Generic Goals (GG) and Specific Goals (SG). The GG and SG include several Generic Practices (GP) and Specific Practices (SP). When all child nodes of a node are covered, it means that the node has been accomplished.

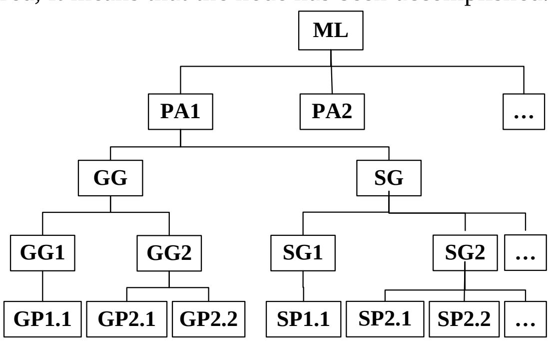

Fig. 1. Logical structure of CMMI.

ISO/IEC 9126 is an attribute-oriented information system quality model. It was enacted in 1991 and revised in 2001 to form ISO/IEC 9126: 2001. ISO/IEC 9126: 2001 includes the quality model ISO/IEC 9126-1, external measurement ISO/IEC 9126-2, internal measurement ISO/IEC 9126-3 and use quality measurement ISO/IEC 9126-4, which was divided into three levels: quality characteristics, quality sub-characteristics and metrics. ISO/IEC 9126-4 includes three use quality characteristics and fifteen use quality sub-characteristics. The external quality and internal quality include six quality characteristics and twenty-eight quality sub-characteristics, as shown in Figure 2.

CMMI is a model to measure the capability of software development organization. And the computation formula of ISO/IEC 9126 is $X=1-A/B$, which A is the number of functions in which problems are detected in the evaluation and B is the number of functions checked. Neither of them is accurate enough. Besides, these models or standards are not proposed for military information systems, so it is difficult to implement and promote them in the development of military information systems. Therefore, the development process net assessment model of teleoperation system established in this paper is mainly based on the national military software standards in China to ensure the correctness of the model.

According to total quality management theory, quality is formed during the development process. And the five factors affecting system quality are 4M1E. Similarly, these factors are also distributed in 4M1E for an information system. The following national military standards are corresponding to 4M1E in the development process.

1) Man: "Capability Maturity Model for Military Software Development (GJB 5000A-2008)" [26] defines the core practices of management and engineering process in software development and maintenance. Just like CMMI, it divides the capability maturity into five levels. There are four kinds of management practices: support management, project management, engineering management and process management. It also includes twenty-two process areas. It is consistent with CMMI in the division of software capability maturity and the definition of process areas.

2) Machine: "Requirements for Military Software Support Environment Acquisition (GJB 3181-1998)" [27] defines the steps, methods and principles to select military software support environment. The definition of software support environment in GJB 3181-1998 is the operational and support software that used for military system development. Generally, it contains the tools for software development, software testing, software support, maintenance, modification, configuration management and resource management. The software support environment consists of software development support environment and software running support environment.

3) Material: "Safe Subset of C Language for Space Armament Software (GJB 5369-2005)" [28] defines the coding standard of C language for aerospace information systems. GJB 5369-2005 divides the program code into fifteen classes. Each class is further divided into recommended subclass and forcing subclass. There are a total of ninety-eight forcing subclasses and forty recommended subclasses. "General Requirements for Military Software Development Documentation (GJB 438B-2009)" [29] defines the structure, format and content of software development process documents. There are a total of twenty-eight documents including operational concept description, software configuration management plan, software test plan, software quality assurance report, requirement specification and so on.

4) Method: "Management Requirements of Military Software Developable Project (GJB 2115A-2013)" [30] defines the process and requirement for military software project management. It divides the software project management process into project establishment phase, contract signing phase, development phase and acceptance phase. It includes eleven management requirements such as project management, development process management, configuration management, document management, resource management, risk management and so on.

5) Environment: "Military Software Support Environment (GJB 2694-1996)" defines the basic requirements of the host computer system, military software development support environment and running support environment.

The development process net assessment model established in this paper is based primarily on the above standards. In addition, some factors that affect system quality but not mentioned in these standards are taken into consideration. Corresponding to the 4M1E, this net assessment model consists of five classes. The first is the organizational maturity. The second is the environment, such as the social environment (international situation, laws and regulations and national policies), physical environment, hardware, development support environment, etc. The third is management, such as risk management, document management, configuration management, resource management etc. The fourth is the software code based on the coding rules. The fifth is the software process documents, such as requirements document, design document, coded document, etc. As shown in TableⅡ.

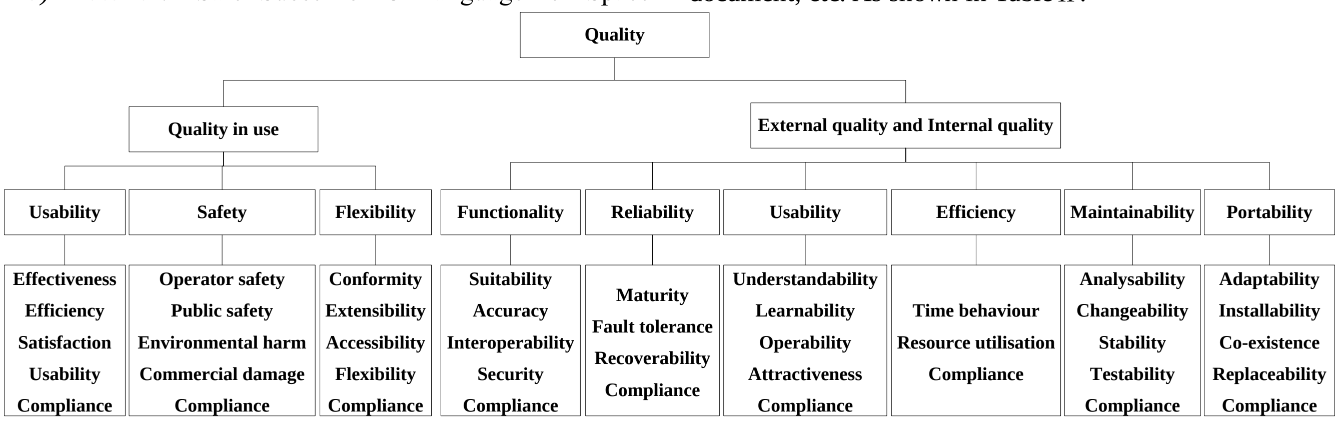

Fig. 2. External and internal quality model of ISO/IEC 9126.

TABLE Ⅱ
CLASSES AND SUBCLASSES OF DEVELOPMENT PROCESS NET ASSESSMENT MODEL

Classes	Subclasses	Total
Organization	MA, PPQA, PMC, PP, REQM, DAR, IPM, OPD, OPF, OT, PI, RD, TS, VAL, VER, OPP, QPM, CAR, OPM	19
Environment	Social Environment, Physical Environment, Hardware Environment, Development Support Environment	4
Management	Project Management, Development Process Management, Configuration Management, Document Management, Resource Management, Risk Management, Quality Management, Agreement Management, Acceptance Management, Software Stereotype Management, Contractor Management	11
Code	Declaration or Definition, Code Writing, Branch Control, Pointer Using, Jump Control, Computing, Procedure Call, Statement Using, Call Return, Program Annotation, Cycle Control, Type Conversion, Initialize, Comparison Judgment, Variable Using	15
Document	Requirement Analysis Document, Design Document, Coding Document, Testing Document, Operation and Maintenance Document	5

TABLE Ⅲ
ELEMENTS OF RISK MANAGEMENT SUBCLASS

No	Elements
1	Whether the risk managers and their responsibilities have been defined clearly?
2	Whether there is the risk management plan?
3	Whether there is the risk management strategy in risk management plan?
4	Whether the risks have been identified and analyzed according to the risk management plan and the risk coefficient has been determined?
5	Whether there is the mitigation measure for unacceptable risks?
6	Whether the risks have been identified and monitored regularly?
7	Whether the risks have been identified and monitored at milestone points?
8	Whether the risks have been identified and analyzed according to the actual situation of the project and external mutation factors at any time?
9	Whether the new risks are identified in time?
10	Whether the risks that have occurred or disappeared are closed in time?
11	Whether the risk coefficient and risk level have been adjusted in time?
12	Whether the risk response has been initiated as rules in time?
13	Whether the risk responses have been tracked until closure?
14	Whether the risk monitoring information has been communicated to project personnel and stakeholders in time?
15	Whether the risk management record is complete and has been managed and preserved throughout the project life cycle?

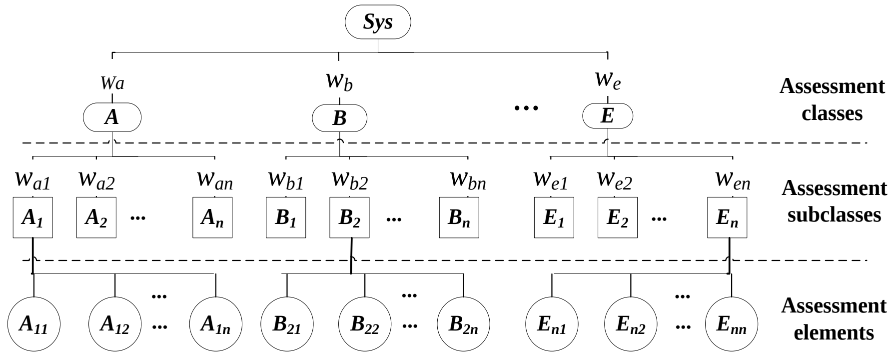

Fig 3. Tree-shaped multidimensional net assessment model.

There are thirty-eight military software standards related to teleoperation system. In order to control the quality of the information system more accurately, the subclasses in Table Ⅱ must be divided further according to the corresponding standards until got the Boolean assessment elements to avoid the ambiguous assessment. For example, the risk management subclass of Management class needs to be divided further. By searching for the relevant standards, the standard of General Requirements for Military Software Quality Assurance (GJB 439A-2013) [31] defines that there are fifteen Boolean elements included in the risk management subclass. As shown in Table Ⅲ.

C. Net Assessment Method

The development process net assessment model established in Section *B* consists of assessment classes, assessment subclasses, and assessment elements that form a tree-shaped multidimensional model, as shown in Figure 3. The type of its leaf nodes is Boolean that can be assigned False or True directly. Where *Sys* represents the overall quality of the system, *w* is the weight coefficient, ***A, B, ..., E*** are the assessment classes.

Firstly, the NAM is used to determine the weight *w* of each assessment class and assessment subclass. Then the quantitative trustworthiness value of the system quality assessment can be calculated by assigning False or True to each assessment element. The trustworthiness value of teleoperation system is defined as Eq. (1).

$$Sys = \sum_{i=1}^{n} w_q * w_{qi} * \frac{t}{n},\ q = (a,b,c,d,e) \quad (1)$$

Where n is the number of leaf nodes of one assessment subclass, t is the number of assessment elements that are valued True.

At present, multi-attribute decision-making algorithms consist of three kinds: subjective weighting method, objective weighting method and combined weighting method. The subjective weighting method depends on the subjective judgment of the decision maker, which leads to the subjectivity of weight coefficient. The Delphi method and AHP are the widely used subjective weighting methods. The objective weighting method has stronger mathematical theoretical basis compared with the subjective weighting method. However, it is easy to ignore the perception of the importance degree of the attribute in the actual decision-making. EWM, dispersion maximization method, principal component analysis method and multi-objective programming method are widely used. In order to overcome the shortcomings of subjective weighting method and objective weighting method, the combination weighting method is a comprehensive method that takes into consideration the subjective evaluation of decision makers and objective decision information.

This paper combines AHP and EWM to propose the NAM. Firstly, the subjective weight is solved by AHP and the objective weight is solved by EWM. Then the subjective weight and objective weight are brought together to overcome the shortcomings of each single method, thus to improve the accuracy of the weighting result. The NAM can be subdivided into the following steps.

1) The establishment of reciprocal judgment matrix.

Each assessment class and assessment subclass should be compared with others in the net assessment model. This paper uses the 1-9 scale method to construct the reciprocal judgment matrix. This method is defined in Table Ⅳ.

TABLE Ⅳ
DEFINITION OF 1-9 SCALE METHOD

Numerical rating	Verbal judgments of preferences
1	Equally preferred
2	Equally to moderately
3	Moderately preferred
4	Moderately to strongly
5	Strongly preferred
6	Strongly to very strongly
7	Very strongly preferred
8	Very strongly to extremely
9	Extremely preferred

If matrix $\boldsymbol{A}$ meets the following equation:

$$\boldsymbol{A}=(a_{ij})_{n\times n},\, a_{ii}=1\wedge a_{ij}*a_{ji}=1\wedge(i,j=1,2,...,\mathrm{n}).$$

Then, the judgment matrix $\boldsymbol{A}$ is called the reciprocal judgment matrix.

2) Consistency checking of reciprocal judgment matrix.

Usually, consistency checking is carried out by solving the largest eigenvalue of reciprocal judgment matrix $\boldsymbol{A}$.

Firstly, sum reciprocal judgment matrix $\boldsymbol{A}$ by the column using the Eq. (2).

$$\boldsymbol{B}=(b_{ij})_{n\times n}, b_{ij}=\frac{a_{ij}}{a_j}, a_j=\sum_{i=1}^{n}a_{ij}, (j=1,2,....,\mathrm{n}) \tag{2}$$

Then, sum matrix $\boldsymbol{B}$ by the row using the Eq. (3).

$$b_i=\sum_{j=1}^{n}b_{ij}, (i=1,2,....,\mathrm{n}) \tag{3}$$

Define $\boldsymbol{U}$ is the eigenvector of matrix $\boldsymbol{A}$, which can be solved by the following equation. That $\boldsymbol{U}$ is the weight vector.

$$\boldsymbol{U}=(u_1,u_2,...u_i,u_n)^T, u_i=\frac{b_i}{n}$$

Define CR is the consistency ratio of matrix $\boldsymbol{A}$, which can be solved using Eq. (4). If CR is less than or equal to 0.1, it means that matrix $\boldsymbol{A}$ passes the consistency checking.

$$CR=\frac{\lambda_{\max}-n}{RI*(n-1)},\ \lambda_{\max}=(\boldsymbol{A}\times\boldsymbol{U})/n \tag{4}$$

Where $\lambda_{\max}$ is the largest eigenvalue of reciprocal judgment matrix $\boldsymbol{A}$, RI is the average random consistency index. Almost all papers only give RI value below the 15th order matrix. According to the calculation principle of RI, the code to calculate the RI value of any matrix in Matlab is set forth in annex.

3) Solving the objective weight using EWM.

According to the definition of EWM, the entropy value of each element can be calculated using Eq. (5).

$$e_j=-k\sum_{i=1}^{n}t_{ij}\ln t_{ij} \tag{5}$$

$$t_{ij}=a_{ij}\Big/\sum_{i=1}^{n}a_{ij}, (j=1,2,...n), k=1/\ln n$$

Then the weight vector $\boldsymbol{V}$ can be calculated using Eq. (6).

$$\boldsymbol{V}=(v_1,v_2,...v_i,v_n)^T, v_j=(1-e_j)\Big/\sum_{j=1}^{n}(1-e_j) \tag{6}$$

4) *Eliminate cognitive blindness of* $\boldsymbol{U}$.

Assuming each expert has same understanding of the elements in the net assessment model. The average awareness matrix $\boldsymbol{P}$ can be defined as Eq. (7).

$$\boldsymbol{P}=(p_{ij})_{n\times n}=(u_1+u_2+u_3+u_4+u_5)/5 \tag{7}$$

Define the uncertainty of the expert on each element is "Cognitive Blindness" [32]. We define the cognitive blindness matrix is $\boldsymbol{C}$. It can be calculated using Eq. (8).

$$\boldsymbol{C}=(c_{ij})_{n\times n}=\frac{\left|\begin{array}{l}[\max(u_1,u_2,u_3,u_4,u_5)-\boldsymbol{P}]+\\ [\min(u_1,u_2,u_3,u_4,u_5)-\boldsymbol{P}]\end{array}\right|}{2} \tag{8}$$

Define the total recognition matrix of five experts on an element is $\boldsymbol{R}$. It can be calculated using Eq. (9).

$$\boldsymbol{R}=(r_{ij})_{n\times n}=\boldsymbol{P}\times(1-\boldsymbol{C}) \tag{9}$$

Define the final subjective weight vector is $\boldsymbol{X}$. It can be normalized using Eq. (10).

$$\begin{gathered}\boldsymbol{X}=(x_1,x_2,...,x_i,x_n)\\ x_i=r_{ij}\Big/\sum_{i=1}^{n}r_{ij}\ (j=1,2,...n)\end{gathered} \tag{10}$$

5) *Eliminate cognitive blindness of* $\boldsymbol{V}$.

Define the final objective weight vector is $\boldsymbol{Y}$. It can be calculated following the step (4).

6) Combination of subjective and objective weights.

Define the final weight vector is $\boldsymbol{W}$. It can be calculated using Eq. (11).

$$\begin{gathered}W=(w_1,w_2,...,w_j,w_n),\\ w_j=x_j*y_j\Big/\sum_{j=1}^{n}x_j*y_j\end{gathered} \tag{11}$$

Then the vector $\boldsymbol{W}$ is called the final weight vector of the net assessment model.

IV. CASE ANALYSIS

TABLE Ⅴ
RECIPROCAL JUDGMENT MATRIXES

Expert	*M1*	*M2*	*M3*	*M4*	*M5*
Reciprocal	1.0 1/2 1/3 1/5 1/4	1/1 1/3 1/4 1/3 1/2	1/1 1/3 5/1 1/1 5/1	1/1 1/3 1/5 1/3 1/2	1/1 1/4 5/1 1/1 5/1
Judgment	2/1 1/1 3/1 1/2 1/1	3/1 1/1 2/1 1/2 1/1	3/1 1/1 5/1 1/1 3/1	3/1 1/1 1/4 1/1 4/1	4/1 1/1 5/1 1/1 4/1
Matrix	3/1 1/3 1/1 1/4 1/3	4/1 1/2 1/1 1/3 1/2	1/5 1/5 1/1 1/3 1/2	5/1 4/1 1/1 3/1 2/1	1/5 1/5 1/1 1/3 1/2
	5/1 2/1 4/1 1/1 2/1	3/1 2/1 3/1 1/1 2/1	1/1 1/1 3/1 1/1 3/1	3/1 1/1 1/3 1/1 2/1	1/1 1/1 3/1 1/1 4/1
	4/1 1/1 3/1 1/2 1/1	2/1 1/1 2/1 1/2 1/1	1/5 1/3 2/1 1/3 1/1	2/1 1/4 1/2 1/2 1/1	1/5 1/4 2/1 1/4 1/1

This paper employs the teleoperation system for CE-3 deep space mission as a case study. The development process of teleoperation system follows national military standard of GJB 5000A-2008 in China. Its capability maturity level for military software development is ML4. It means the software development process has been managed quantitatively.

Weighting each assessment class

Five experts were invited to weight the assessment classes and subclasses of the net assessment model. And the NAM is utilized to solve the weight coefficient of each assessment index. There are five assessment classes including Organization, Environment, Management, Code and Documentation, as shown in Table Ⅱ. The experts assign value to the each assessment class using 1-9 scale method. The reciprocal judgment matrixes of the five experts are ***M1, M2, M3, M4***, and ***M5***, as shown in Table Ⅴ. The consistency ratio *CR* of each matrix is shown in Table Ⅵ. The weight vector ***U*** and the final subjective weight vector ***X*** of AHP, the weight vector ***V*** and the final objective weight vector ***Y*** of EWM, and the final weight vector ***W*** are shown in Table Ⅶ.

TABLE Ⅵ
THE CONSISTENCY RATIO *CR* OF EACH MATRIX

Expert	*M1*	*M2*	*M3*	*M4*	*M5*
CR	0.0442	0.0533	0.0631	0.0792	0.0811

TABLE Ⅶ
THE ***U***, ***X***, ***V***, ***Y*** AND ***W*** SOLVED BY NAM

	Weight Vector				
U	0.0655	0.2080	0.1050	0.3883	0.2332
	0.0775	0.2150	0.1502	0.3571	0.2003
	0.2523	0.3609	0.0576	0.2436	0.0857
	0.0626	0.2111	0.4385	0.1763	0.1115
	0.2271	0.3960	0.0559	0.2481	0.0729
X	0.1376	0.2786	0.1514	0.2898	0.1426
V	0.1323	0.1915	0.2435	0.1742	0.2586
	0.1240	0.2535	0.2821	0.1376	0.2028
	0.3851	0.1753	0.1259	0.1027	0.2111
	0.0929	0.3705	0.1444	0.2330	0.1592
	0.4119	0.1907	0.1074	0.1065	0.1835
Y	0.2286	0.2324	0.1818	0.1513	0.2060
W	0.1597	0.3287	0.1398	0.2226	0.1492

Comparison with AHP and EWM

The correlation coefficient between two matrixes reflects the similarity of two matrixes.

Define the inverse matrix ***F*** can be solved based on the final weight vector ***W*** using Eq. (12).

$$\boldsymbol{F} = (f_{ij})_{n\times n} = \frac{w_i}{w_j}(i, j = 1, 2, \ldots n) \tag{12}$$

Define the correlation coefficient *r* between matrix ***A*** and ***B*** can be solved using Eq. (13).

$$r = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(a_{ij}-\bar{A})*(b_{ij}-\bar{B})}{\sqrt{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}(a_{ij}-\bar{A})^2\right)*\left(\sum_{i=1}^{n}\sum_{j=1}^{n}(b_{ij}-\bar{B})^2\right)}} \tag{13}$$

$$\bar{A} = \frac{a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}}, \bar{B} = \frac{b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}b_{ij}}, (i, j = 1, 2, \ldots, n)$$

We use the matrixes in Table Ⅴ as the experimental data. And the corresponding weight vectors are ***X, Y,*** and ***W***, as shown in Table Ⅶ. The inverse matrix ***F*** solved using Eq. (12) is shown in Table Ⅷ.

TABLE Ⅷ
THE INVERSE MATRIX ***F***

Weight Vector	Inverse Matrix ***F***				
X	1.0000	0.4939	0.9089	0.4748	0.9649
	2.0247	1.0000	1.8402	0.9614	1.9537
	1.1003	0.5434	1.0000	0.5224	1.0617
	2.1061	1.0402	1.9141	1.0000	2.0323
	1.0363	0.5118	0.9419	0.4921	1.0000
Y	1.0000	0.9836	1.2574	1.5109	1.1097
	1.0166	1.0000	1.2783	1.5360	1.1282
	0.7953	0.7823	1.0000	1.2016	0.8825
	0.6619	0.6510	0.8322	1.0000	0.7345
	0.9011	0.8864	1.1331	1.3615	1.0000
W	1.0000	0.4859	1.1423	0.7174	1.0704
	2.0582	1.0000	2.3512	1.4766	2.2031
	0.8754	0.4253	1.0000	0.6280	0.9370
	1.3939	0.6772	1.5923	1.0000	1.4920
	0.9343	0.4539	1.0672	0.6703	1.0000

The standard deviation of a vector reflects its dispersion. If a vector has a higher standard deviation, it means that its elements have higher discrimination. In other words, it is easier to make a judgment. The standard deviation *std* of a vector can be solved using Eq. (14).

$$std = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}} \tag{14}$$

The correlation coefficient between inverse matrix and the initial matrix calculated using Eq. (13) and the standard deviation of the final weight vector calculated using Eq. (14) are shown in Table Ⅸ. Table Ⅸ illustrates the standard deviation *std* of NAM is larger than AHP and EWM.

TABLE Ⅸ
CORRELATION COEFFICIENT MATRIX AND STD

Method	Correlation Coefficient Matrix	Std
AHP	0.6302 0.6554 0.5113 0.2786 0.5942	0.0771
EWM	0.4704 0.5239 0.2148 0.3805 0.1749	0.0339
NAM	0.3795 0.3998 0.6733 0.1176 0.7358	0.0789

Figure 4 is the stacked bar chart of correlation coefficient.

It shows that the weight vector calculated by the NAM has intermediate correlation with the reciprocal judgment matrixes in Table Ⅴ. Because NAM has combined the advantages of AHP and EWM, therefore, the quantitative result obtained by the NAM is more accurate and reasonable. Comparison shows that NAM proposed in this paper is better than AHP and EWM.

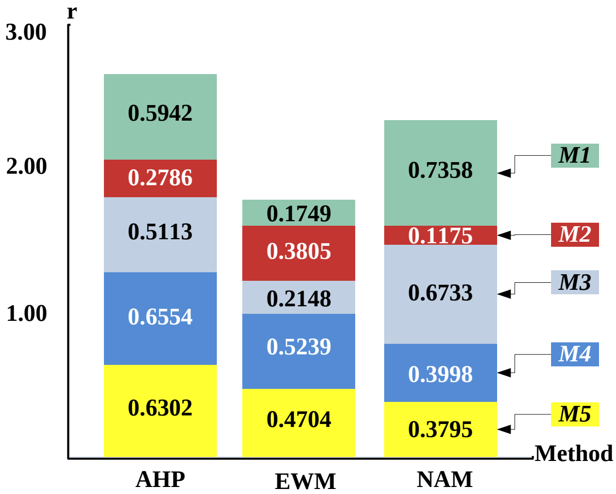

Fig 4. The stacked bar chart of correlation coefficients

Weighting each subclass of management assessment class

Taking the management assessment class as an example, it has eleven subclasses as shown in Table Ⅱ. Due to the limited space, this paper only gives two experts' reciprocal judgment matrix of management assessment class, as shown in Table Ⅹ.

TABLE Ⅹ
JUDGMENT MATRIX OF MANAGEMENT ASSESSMENT CLASS

Expert	Reciprocal Judgment Matrix										
M1	1/1	1/1	2/1	2/1	3/1	1/1	2/1	2/1	2/1	4/1	3/1
	1/1	1/1	3/1	2/1	2/1	1/2	3/1	3/1	2/1	3/1	4/1
	1/2	1/3	1/1	1/3	1/2	1/3	1/1	1/2	1/2	2/1	2/1
	1/2	1/2	3/1	1/1	1/1	1/2	2/1	1/1	2/1	2/1	3/1
	1/3	1/2	2/1	1/1	1/1	1/2	2/1	1/1	1/3	2/1	3/1
	1/1	2/1	3/1	2/1	2/1	1/1	3/1	2/1	1/1	4/1	4/1
	1/2	1/3	1/1	1/2	1/2	1/3	1/1	1/1	1/2	2/1	2/1
	1/2	1/3	2/1	1/1	1/1	1/2	1/1	1/1	1/2	2/1	2/1
	1/2	1/2	2/1	1/2	3/1	1/1	2/1	2/1	1/1	2/1	2/1
	1/4	1/3	1/2	1/2	1/2	1/4	1/2	1/2	1/2	1/1	1/1
	1/3	1/4	1/2	1/3	1/3	1/4	1/2	1/2	1/2	1/1	1/1
M2	1/1	2/1	2/1	1/1	3/1	2/1	3/1	1/1	3/1	4/1	2/1
	1/2	1/1	2/1	3/1	2/1	1/2	2/1	4/1	1/1	4/1	4/1
	1/2	1/2	1/1	2/1	1/3	1/2	2/1	1/1	2/1	1/1	3/1
	1/1	1/3	1/2	1/1	1/1	1/1	2/1	1/1	3/1	4/1	3/1
	1/3	1/2	3/1	1/1	1/1	1/2	2/1	1/1	1/4	3/1	2/1
	1/2	2/1	2/1	1/1	2/1	1/1	4/1	3/1	1/2	3/1	4/1
	1/3	1/2	1/2	1/2	1/2	1/4	1/1	1/2	1/1	3/1	2/1
	1/1	1/4	1/1	1/1	1/1	1/3	2/1	1/1	1/3	1/1	2/1
	1/3	1/1	1/2	1/3	4/1	2/1	1/1	3/1	1/1	3/1	1/1
	1/4	1/4	1/1	1/4	1/3	1/3	1/3	1/1	1/3	1/1	2/1
	1/2	1/4	1/3	1/3	1/2	1/4	1/3	1/2	1/1	1/2	1/1

The weight vector solved using MATLAB is ***W***= (0.0858 0.1860 0.0629 0.1182 0.1093 0.1400 0.0486 0.0727 0.1338 0.0251 0.0176).

Taking the Risk Management assessment subclass as an example, there are 15 Boolean assessment elements, as shown in Table III. The trustworthiness value of the system can be calculated by assigning False or True to each assessment element according to the fact of teleoperation system. According to Eq. (1), the trustworthiness value of risk management subclass is:

$$Sys = 0.1398 * 0.1400 * \frac{15}{15} = 0.019572 \cdot$$

That is the net assessment result. Owing to the limited space, it is inconvenient to show all the judgment matrixes and weight vectors. Finally, trustworthiness value of teleoperation system is 0.9328.

According to the China's Military Software Product Evaluation standard (GJB 2434A-2004) [33], the teleoperation system is the A-level software. If the trustworthiness value is greater than 0.9, it means that this system is trustworthy. So, we believe the teleoperation system is trustworthy.

V. CONCLUSION

The superior teleoperation system is the key to the success of deep space mission directly. It cannot be modified once the deep space exploration mission has launched. So, it must be assessed quantitatively before and during its implementation. At present, the application scope of net assessment has covered military, environment, performance, economic and so on. And it has been used and promoted by scholars in various fields. However, there is still no any research about the net assessment of information systems. The net assessment is more comprehensive and forward-looking compared with traditional evaluation models. An intensive study of net assessment would have enormous significance for the construction of military information system assessment theory and the formulation of corresponding development process improvement measures. Therefore, the investigation about the net assessment of information systems should be paid more attention by the relevant experts and organizations.

1) The development process net assessment model established in this paper is based on China's national military software standards. So, it is more accurate. Besides, it covers the whole software lifecycle and incorporates social environment, economic conditions, policy conditions and other indirect factors into the net assessment model, which is more comprehensive than the traditional assessment model. Based on this study, the teleoperation system development project has passed the China's GJB 9001C-2017 (Corresponding to ISO/IEC 9001) Weapons and Equipment Quality Management System Certification. Moreover, the ground centre controlled "Jade Rabbit" rover via the teleoperation system in CE-3 and CE-4 mission successfully. In the future, the teleoperation system will continue to provide the three-dimensional information display and operation platform for the related configuration items such as terrain construction, visual positioning, mission planning, activity organization planning, planning verification and so on in future deep space missions such as the sampling and return from the lunar surface mission (CE-5) and the Mars exploration

mission. Therefore, the net assessment of teleoperation system in this paper provides a technical framework for military information system development process improvement.

2) The NAM set out in the present paper combines the advantages of AHP and EWM. The quantitative assessment result can be obtained by assigning 0|1 to each assessment element, which is more accurate than traditional qualitative evaluation methods such as holding a project review meeting. In addition, the elements assigned to False are the untrustworthy elements in the development process. So, the untrustworthy elements can be discovered and improved in time.

In this paper, the assessment elements in Organization class and Management class are assigned by artificial means, which contain subjective factors. So, how to extract the trustworthy evidence in the system development process by using formal methods and automation tools will be the next research direction in the future [34].

APPENDIX

The code to calculate the *RI* in Matlab is as follows.

```
for k=1:50
for n=1:1000000
b=[9;8;7;6;5;4;3;2;1;1/2;1/3;1/4;1/5;1/6;1/7;1/8;1/9];
    aa=ceil(17*rand(k));
    for i=1:k
        for j=i:k
            a(i,j)=b(aa(i,j)); a(j,i)=1/(a(i,j)); a(i,i)=1;
        end
    end
    w=ones(1,k);
    for i=1:k
        for j=1:k
            w(i)=w(i)*a(i,j);
        end
    end
    w=w.^(1./k);
    w=w./sum(w);
    L=sum((a*w')./(k.*w'));
    CI(k,n)=(L-k)/(k-1);
end
RI(k)=sum(CI,2)./1000000;
  end
```

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